Laboratory Investigation of Air-Sea Interfacial Properties in Relation to Gas Exchange and Remote Sensing

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LONG-TERM GOALS

Our long range goals for this project are to: 1) understand the effect of various physical and chemical properties of the air-sea interface on gas exchange, and 2) characterize the sea surface texture and turbulent boundary layers. These studies will provide a basis for future work on the active and passive microwave remote sensing of the sea surface and the estimation of surface wind vectors and gas transfer velocities from such information.

OBJECTIVES

This project is an experimental study of wave dynamics, boundary layer turbulence, and gas exchange in a salt-water wind-wave tank. Our objectives are: 1) to relate surface texture and boundary layer turbulence to imposed surface wind stress and gustiness, and atmospheric stability to provide insight into the factors controlling remote sensing of the ocean surface, and 2) to relate direct measurements of air-sea gas fluxes to the surface water chemistry and texture and boundary layer turbulence.

APPROACH

Our approach is to carry out laboratory experiments under controlled conditions, in which we can extensively characterize the state of the fluids and interface. The experiments will be carried out using a new facility, the Air-Sea Interaction Salt-water Tank (ASIST). ASIST is a linear, recirculating wind/wave tank. During these experiments, water surface textures will be characterized using an imaging slope gauge and scanning slope gauge. Turbulence measurements in air and water will be made

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using hot x-films and a conical hot film probe carried by a wave follower. Turbulence measurements and visualization in the water will also be made using particle image velocimetry. Gas exchange will be studied using eddy correlation flux measurements involving fast-response chemical detection for carbon dioxide via IR absorption, and for other gases (such as dimethylsulfide, ammonia, and sulfur dioxide) by chemical ionization mass spectrometry. The key personnel involved in the project are Drs. Eric Saltzman (gas exchange), Mark Donelan (turbulence, wave properties, and remote sensing), and Warren De Bruyn (mass spectrometry).

WORK COMPLETED

The ASIST facility is fully functional and most of the instrumentation to characterize the flow fields, wave properties and chemistry are in place and tested. These include:

1) A Dantec Particle Image Velocimetry system with memory module capable of 1000 images before transfer to mass storage. This corresponds to 500 vector maps (see results below).

2) A Thermal Systems Hot-film/wire Velocimetry system including 4 channels plus a constant current bridge for temperature measurements. This permits point measurements of velocity components to at least 2000Hz in both air and water.

3) A three-point laser elevation gauge (in-house design) for determining surface (wave) elevation and slope. The system is capable of measurements up to 1000Hz.

4) Measurements of CO_2 and H_2O concentrations in the air DC to 5Hz. This system is based on the LI-COR 6262 CO_2 / H_2O infrared analyzer. It will be coupled with the vertical velocity measurements from the hot-film instrument to yield direct "eddy correlation" fluxes of CO_2 and H_2O.

5) C-band dual polarized Doppler radar ("Scatterometer"). This system was designed and built in the Applied Physics Laboratory, University of Washington. It has been installed and tested. The footprint on the surface is about 100 sq. cm. Preparations are being made to correlate its measurements with local wave properties.

The remaining major instruments to be installed later this year are:

1) A chemical ionization mass spectrometer for high speed response to air-borne concentrations of such gases as DMS, NH_3 and SO_2. New software for the spectrometer has been developed to this end.

2) An imaging 2-D slope gauge 50cm x 50cm. The design of this device, which uses 2 RBG cameras to measure both downwind and crosswind slopes at 120Hz, is by Dr. Jochen Klinke, Scripps Institution of Oceanography.

RESULTS

Wind wave tanks provide natural analogs of the air-sea interface although there are some very significant differences in the wind-wave coupling mechanisms. Some processes such as wave breaking appear to scale well provided that there is a sufficiently large range of scales of gravity waves in the spectrum produced by the wind. ASIST has a working section of 16 m length and cross-section of 1 m x 1 m. The working section is constructed of acrylic so that flow visualization is facilitated along the full fetch. In this experiment the water depth was 400 mm and the waves were wind-generated. A constant current of 0.08 m/s in the wind direction was provided by a recirculating pump. This was done to enable the measurement of small scale turbulence with hot film velocimetry (not reported here). The measurements being reported here were made with a Particle Image Velocimetry (PIV) system manufactured by Dantec. In this flow measurement technique the flow is "seeded" with 10 micron neutrally buoyant spheres and a double flash laser system illuminates the flow at 15 Hz with about 1 ms between the members of the pairs of flashes. These image pairs are captured on a CCD camera and cross-correlated in sub-areas of the 10^6 pixel matrix yielding a "map" of velocity vectors in a 62 x 62 matrix at 15 Hz. In this 2-D system only the projections of the vectors in a vertical plane parallel to the tank's long axis are obtained. The area selected was 75.5 mm x 75.5 mm and so the vectors were obtained at a spacing of 1.22 mm. This is an order of magnitude larger than the expected Kolmogorov microscale, but two orders of magnitude smaller than the breaking waves, which are believed to be the principal source of turbulent energy in the "wave zone". This wide range between assumed input scales and those responsible for dissipation to heat augurs well for a defined inertial sub range (ISR), in which the structure function increases as the 2/3 power of the separation distance between velocity pairs according to the Kolmogorov similarity law (see, for example, Dickey and Mellor, 1979).

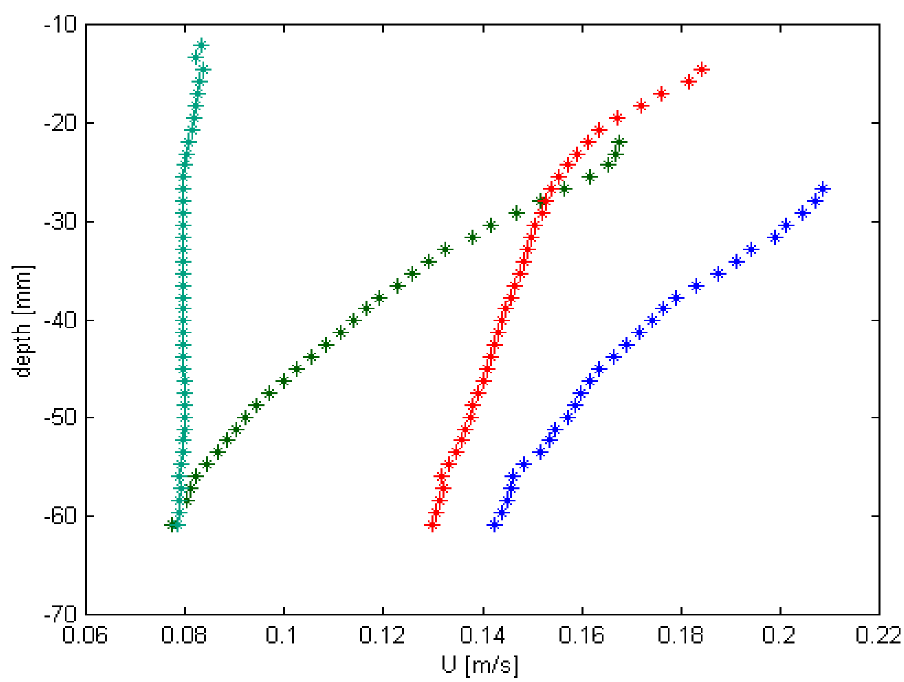

Fig. 1a. Velocity profiles from Particle Image Velocimetry (PIV). The 4 cases are: no wind (cyan); light wind, no breaking (red); moderate wind, some breaking (green); strong wind, intense breaking (blue). In all cases there is an imposed current of 0.08 m/s.

Four runs are reported here, all with an imposed current of 0.08 m/s: 1) no wind (colour on figures is cyan); 2) light wind, waves but no wave breaking (red); 3) moderate wind, some wave breaking (green); 4) strong wind, frequent wave breaking (blue). Figure 1a shows the velocity profiles on linear axes. Measurements are not reported above the deepest troughs, consequently the profiles begin at deeper depths with successively increasing wind. All results are from averages of 500 vector maps or 33 seconds of data.

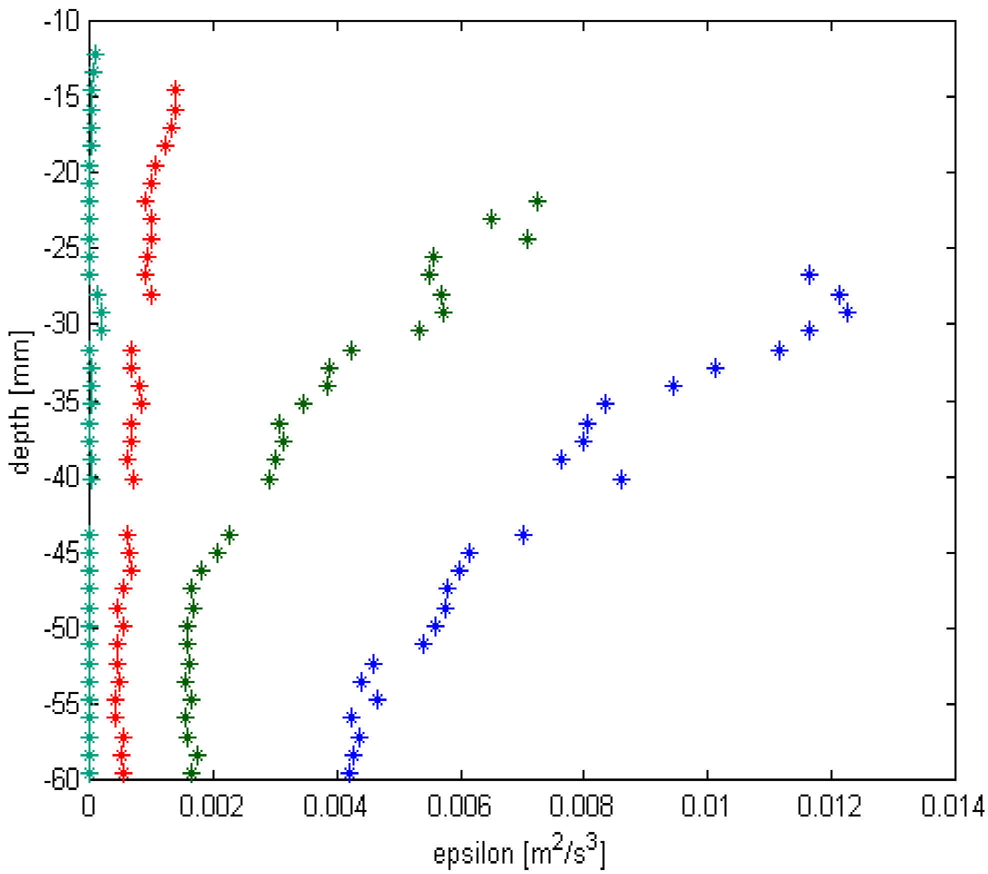

Fig. 1b. Dissipation rate profiles from structure functions using Particle Image Velocimetry (PIV) and structure function analysis. The 4 cases are: no wind (cyan); light wind, no breaking (red); moderate wind, some breaking (green); strong wind, intense breaking (blue).

In Figure 1b structure function ISR estimates of ε are graphed versus depth on linear scales. Note that the values of ε are essentially zero in case 1 (no wind), suggesting that the turbulence generated by the imposed current interacting with the bottom is insignificant compared to that generated by the wind in cases 2,3 & 4. Measurements of the dissipation rate near to the surface will be part of the physical supporting data for gas transfer and radar response measurements.

TRANSITIONS

We expect that this project will eventually result in two types of transitional developments: 1) a flux measurement capability for eddy-correlation measurements of trace gases at sea, and 2) improved algorithms relating the state of the air/sea interface to remotely sensed properties.

RELATED PROJECTS

This project is closely related to a DURIP award for the construction of the ASIST wind/wave facility.